EOS
Transactions, American Geophysical Union
Vol. 65 No. 27 July 3, 1984

Marcel Nicolet, 1984 Bowie Medalist

Eos, Transactions, American Geophysical Union | Vol. 65, No. 27, Pages 425–432 | July 3, 1984

TOPEX: Observing the Oceans From Space

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The vastness and inaccessibility of the oceans make difficult the collection of measurements necessary to develop detailed models of the oceans and an understanding of oceanic dynamics. However, the combination of satellite altimetry and scatterometer wind measurements, technologies developed and demonstrated by the National Aeronautics and Space Administration, together with enhanced in situ measurements, can provide a major improvement in our ability to observe the oceans globally and synoptically. For example, these data could greatly improve the modeling and long-range predictions of global oceanographic and atmospheric anomalies associated with the El Niño/ Southern Oscillation such as occurred in 1982–1983. Hence, the launch of the Ocean Topography Experiment (TOPEX) satellite, which will provide worldwide altimeter data, combined with the initiation of international programs such as the World Climate Research Program, will lead to significant progress in the understanding of oceanic processes on global scales.

Introduction

Satellite altimeters have been improved during their brief 10-year history from the 1-m precision of Skylab to 50 cm for GEOS 3 and a subsequent 5 cm precision for Seasat. The GEOS 3 and Seasat missions demonstrated the potential of satellite altimetry for geodetic and oceanographic applications and have substantially improved our knowledge of the marine geoid. In addition, they have demonstrated the value of the altimeter for studying mesoscale variability of surface geostrophic currents (Figure 1) and have yielded impressive evidence of potential improvement in our understanding of general ocean circulation (Figure 2).

A satellite altimeter measures the satellite-to-sea-surface range by determining the round-trip travel time of a radio pulse transmitted by the altimeter and reflected from the ocean surface. Such measurements, when combined with the orbit height obtained by tracking the satellite, make it possible to determine the topography or shape of the ocean surface. The shape of the ocean surface, which deviates at some points by as much as 100 m from the best-fitting reference ellipsoid, closely approximates an equipotential surface referred to as the marine geoid.

The small deviations (<1 m) of the ocean surface from the marine geoid are caused primarily by quasi-geostrophic currents and tides. Generally speaking, water movements having spatial scales greater than about 50 km (the Rossby radius of deformation) and time scales longer than about a day are in quasi-geostrophic balance to a good first approximation. This means that in lowest order the velocity field is such that the Coriolis force is balanced by the pressure field. Water movement tends to be along, rather than down, the pressure contours, just as winds in the atmosphere circulate around highs and lows. The pressure field in the ocean manifests itself as a slope of the constant-density surfaces in the sea relative to level (equipotential) surfaces apart from the tides. The slope of the sea surface is a direct result of that part of the surface flow field which is geostrophic. As an example, the slope of the ocean surface relative to the geoid across the Gulf Stream is approximately 10^{-5}. It is desirable to measure slopes as small as 10^{-7} across ocean basins. Measurement of these slopes would thus provide direct observation of the major component of large-scale oceanic flow.

Altimeter range measurements, also, can be made over land and ice, providing topographic profiles as well as ice edge location. While other satellite instruments such as scatterometers and radiometers provide ice edge location, ice profiles are nearly impossible to obtain except by altimetry. In addition, the altimeter measures wave height and surface wind speed from the shape and amplitude of the reflected pulse, with an accuracy comparable to that obtained from in situ instrumentation.

Pending governmental approval of the project, NASA plans to launch the Ocean Topography Experiment (TOPEX) satellite in 1989. This satellite will carry an altimeter capable of measuring the satellite-o-sea-surface range with a relative precision of 2–3 cm, and the TOPEX measurement system will provide sea surface topography measurements with an absolute accuracy of 14 cm (Table 1). The primary objective of the TOPEX mission is to collect a 3-year set of sea surface topography data. This data set will be a key to the measurement of time-varying and mean circulation.

Several satellite missions carrying Seasat-class altimeters are being planned for this decade. The U.S. Navy plans to launch GEOSAT in 1984 to complete the task of high-resolution mapping of the marine geoid, which was interrupted by the early demise of Seasat. The absolute accuracy expected for this measurement is approximately 1 m. Consequently, data from GEOSAT will not be sufficiently accurate to determine the global circulation. Coincident with the TOPEX mission, the U.S Navy plans to fly the Navy Remote Ocean Sensing System (N-ROSS) satellite. It will carry a scatterometer (to be provided by NASA) to measure wind speed and direction over the oceans and two scanning radiometers, one to determine sea surface temperature and the other to provide atmospheric corrections for the other instruments as well as information on sea ice extent. The combination of 2 cm precision altimetry from TOPEX and global synoptic wind measurements provided by N-ROSS will allow oceanographers to test hypotheses of the linkage between ocean circulation and winds. The N-ROSS payload also contains a Seasat-class altimeter to measure wave height and to map mesoscale oceanographic features; however, the mission is not designed to provide topographic measurements adequate for the measurement of mean ocean circulation. TOPEX is the only proposed altimetric mission designed to provide the data necessary to study mean ocean circulation as well as variability at all length scales.

The European Space Agency, France, and Japan all have plans to launch Seasat-class altimeters before the end of this decade. Currently, the United States and France are discussing the feasibility of merging TOPEX and the French altimetric mission, Poseidon. More details on this are given below.

TABLE 1. TOPEX Height Measurement Error Budget

ERROR SOURCES	UNCERTAINTY (cm, 1σ)	DECORRELATION (HOURS)
ALTIMETER		
• INSTRUMENT NOISE	2.0	1
• RMS DRIFT	2.0	70 (WANY DAYS)
MSDA		
• IN SEAS		
• IN RIVERS	3.0	300–1000
• TROPOSPHERE – DRY	1.0	300–1000
• TROPOSPHERE – WET	1.5	1000
• IONOSPHERE	1.5	100
ORBIT		60
• ATMOSPHERIC DRAG		
• SOLAR RADIATION	1.0	>10,000
• EARTH RADIATION	1.0	>10,000
• GM	<1.0	10,000
• GRAVITY	2.0	10,000
• EARTH AND OCEAN TIDES	10.0	10,000
• STATION AND SPACECRAFT CLOCK	1.0	10,000
• TROPOSPHERE	1.0	10,000
• STATION LOCATION	1.0	10,000
• INNER GRDCH ATMOSPHERE	5.0	10,000
RSS ABSOLUTE ERROR	5.0	10,000
	13.3	
MAJOR ASSUMPTIONS		
1. DUAL FREQUENCY ALTIMETER		
2. DUAL FREQUENCY RADIOMETER		
3. UPGRADED DORIS TRANSIT TRACKING SYSTEM, 40 STATIONS		
4. ALTIMETER DATA AVERAGED OVER 2 S		
5. SIGNIFICANT WAVE HEIGHT = 2 m		
6. TRIAXIAL ORBIT SOLUTION BASED ON LIMITED TRACKING/TRACKER COMPARISONS		
7. 1000 m ALTITUDE		
8. NO ATMOSPHERIC GLOB DATA, NO RAIN		
9. IMPROVED GRAVITY MODEL		
10. NO SEA SURFACE PRESSURE FROM NMC ANALYSIS CHARTS		
11. 100 pa BAROCLINIC CLOCK		

Shown here are the dominant errors in the determination of the ocean height above a reference surface using a single TOPEX height measurement. The decorrelation distance is a typical length scale associated with the error source.

Need for TOPEX

The past few decades have witnessed significant progress toward understanding the ocean circulation. In the years since World War II, oceanographers have developed a good understanding of the fundamentals of the physics of fluid flow, and now geophysical fluid dynamics provide a theoretical framework into which could be placed observations from a number of novel instruments that have become available recently. The computer has made possible the creation of numerical models that describe the dynamics of entire ocean basins and has provided the means to process large data sets necessary to initialize and drive these models.

As a result of the advances in computer and instrumentation technology, the oceanographic community is now ready to undertake the fundamental problem of understanding the general circulation of the world's oceans. As recently as 10 years ago, too little was known about circulation, and instrumentation was unavailable to attempt a program such as mapping the global general circulation. However, the development of altimeters and scatterometers has provided the capability to measure globally and nearly synoptically sea surface topography and winds, and satellite-borne microwave radiometers provide the necessary corrections for atmospheric influences on the altimetric and scatterometer data. Data from these instruments, when coupled with conventional and novel in situ measurement techniques such as acoustic tomography, inverted echo sounders, satellite-tracked drifting buoys and floats, and improved current meters and hydrographic instruments, as well as programs to measure passive trace elements such as fluorocarbons or tritium, significantly enhance the feasibility of understanding global circulation.

Knowledge of the mean and time-varying components of global circulation would help provide the answers to a number of questions being asked by society:

1. What is the role of the ocean in determining our present global climate and its fluctuations. For example, the rate at which the oceans will absorb the increasing amount of CO_2 being emitted into the atmosphere and an understanding of the atmosphere/ ocean interaction during the El Niño/ Southern Oscillation phenomena are topics of critical interest.
2. What is the trajectory and ultimate fate on long time scales of wastes in the ocean associated with radioactive materials.
3. What factors control and modulate the oceanic upwelling that supports the world's fisheries? The answers to questions such as these can be obtained only after the general circulation of the oceans is better described and understood.

Climatologists and meteorologists are currently forced to parameterize the effect of the ocean on climate and weather in grossly oversimplified ways. Ultimate understanding of how climate and weather are controlled and changed requires first a comprehensive description of the global scale ocean circulation and, second, a much deeper understanding of its physics and chemistry.

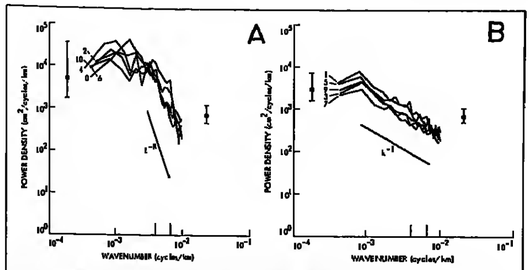

Fig. 1 Spectra of the sea surface height variability obtained from Seasat altimeter height data in (*a*) high-energy areas (near major currents) and (*b*) low-energy areas. The 10 labeled curves are from different areas in the world's oceans. The error bars are 95% confidence limits. The left error bar in each figure is for wavelengths greater than 250 km, and the right one is for wavelengths shorter than 250 km. The two large tick marks on the wave number axis indicate the wavelengths of 150 and 250 km, respectively. These spectra show that altimeter data provides information on the statistics of mesoscale variability which can be used by models of ocean circulation. (From L. L. Fu, On the wave number spectrum of mesoscale variability observed by the seasat altimeter (*J. Geophys. Res., 88*, 4331–4342, 1983.)

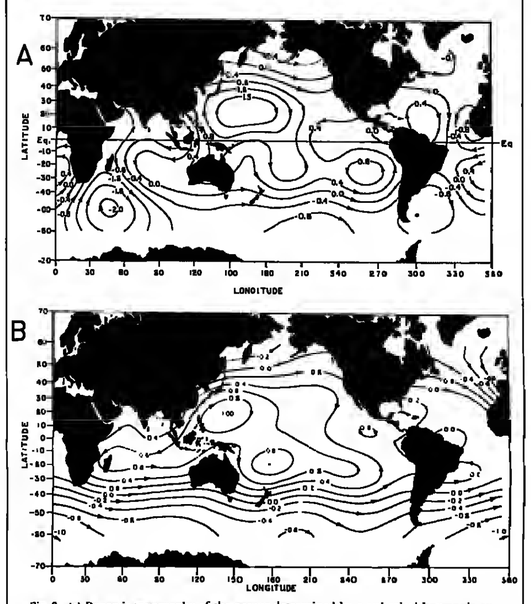

Fig. 2 (*a*) Dynamic topography of the oceans determined by a spherical harmonic expansion complete to degree and order six of the difference between Seasat altimeter height measurements and the best available long wavelength geoid from the Goddard Space Flight Center. (*b*) An equivalent expansion of dynamic topography based on hydrographic data and published by S. Levitus. While there are obvious differences in the two maps (for which there are plausible explanations), their striking similarity is tantalizing evidence of the potential of a mission such as TOPEX. (From C. K. Tai and C. Wunsch, An estimate of global absolute dynamic topography, *J. Phys. Oceanogr.*, in press, 1983.)

Mission Objectives

The TOPEX mission design is based upon studies of GEOS 3 and Seasat results and of known oceanic characteristics. TOPEX will provide altimeter data over nearly all the world's oceanic areas for a period of 3 years. However, the spacecraft will carry sufficient expendables to allow an additional 2 years of operation. The TOPEX data set will be augmented with the necessary ancillary and corrective data to allow scientists to compute global sea surface topography maps accurate to about 14 cm at intervals of the satellite ground track repeat period (nominally 10 days). Differences of these maps will reveal the time-varying component of ocean circulation. The 3 to 5 year data set will provide over a hundred of these maps which can be averaged to provide a multi-year mean sea surface accurate to a few centimeters. Differences of this mean surface from the marine geoid will yield a global map of mean geostrophic flow. While the production of maps

Article (cont. on p. 434)

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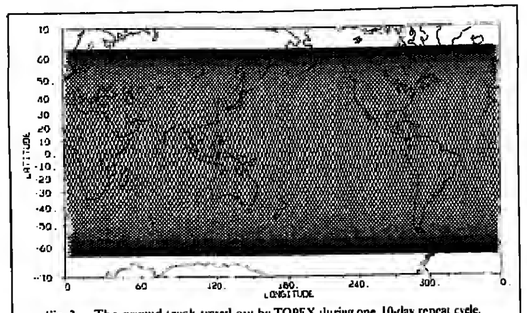


Fig. 3. The ground track traced out by TOPEX during one 10-day repeat cycle.

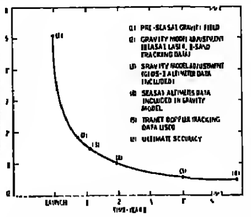


Fig. 4. Evolution of Seasat orbit determination accuracy. Following the launch of Seasat, significant increases in orbit determination accuracy resulted from the development of and subsequent improvements to a gravity model tailored for the Seasat orbit. Current orbit determination accuracy for Seasat (~40 cm) is not far from that required for TOPEX, and the timely development of the necessary models and methodology to achieve the TOPEX objectives appears feasible.

of global mean geostrophic flow requires a geoid with greater accuracy than is currently available except at wavelengths greater than about 10,000 km, maps of the time-varying circulation are independent of the geoid and could be produced immediately from TOPEX data. Because the ocean varies on all length and time scales, the quantification of its variability in a statistical sense is important to the development of ocean circulation models.

At first, mean circulation will be studied at long wavelengths and on a regional basis in areas where high-precision geoids exist. Shipboard gravity surveys can be carried out before, during, and after the TOPEX mission to increase the number of local geoids suitable for mean circulation studies. However, solution of the general problem of global mean circulation requires a global geoid with an accuracy of 2–5 cm on length scales of a few hundred kilometers to the size of the ocean basins. The short and intermediate wavelength portion of such a geoid could be produced by the Geopotential Research Mission, which NASA hopes to begin in the early 1990's (*Eos*, October 25, 1983, p. 6091. Satellite tracking data and surface gravity data currently available have the potential to improve the long wavelength portion of the geoid to useful accuracy for mean circulation studies.

Ancillary Programs

While collection and verification of a 3-year set of global altimeter data is the primary objective of the TOPEX mission, this data set by itself is not adequate to determine the general circulation. A program of in situ data collection must be underway simultaneously. This program should include ships and drifting buoys deployed on a global scale to gather hydrographic, gravimetric, near-surface velocity, and chemical tracer data. In particular, the buoys and neutrally buoyant floats with satellite communications links are needed for direct observations of the flow field over large areas and long time periods. In a few areas of special interest, regional observing programs using ships, moored current meters, floats, temperature recorders, tide gauges, and other in situ instruments will be required. These regional areas would be places such as the Straits of Florida or the Drake Passage where local information would make a direct and immediate contribution to a knowledge of larger circulation scales.

Clearly, an in situ program on this scale will require international cooperation and participation. The worldwide meteorological and oceanographic community, under the auspices of the International Council of Scientific Unions, the U.N. Educational, Scientific, and Cultural Organization, and the World Meteorological Organization has underway a program called the World Climate Research Program (WCRP). The major oceanographic elements of WCRP include the World Ocean Circulation Experiment (WOCE), the Tropical Oceans/Global Atmospheres Experiment (TOGA), and a global ocean monitoring program for repeated measurements of the internal structure of the ocean in critical regions. Overall, WCRP is equivalent in scope to the Global Weather Experiment of 1979–1980. The TOPEX program will be closely coordinated with WOCE and TOGA and will provide a critical source of data for WOCE. TOPEX in turn will benefit from the extensive in situ observations planned for these experiments.

The general circulation of the ocean is known to be forced by winds and by air-sea transfer of heat and fresh water. To understand details of this forcing as well as to test our ability to compute circulation from the forcing by winds, synoptic global wind fields will be required. The only feasible way to obtain these is with a satellite-borne wind field scatterometer. This instrument, which was proven on Seasat, will be carried by the U.S. Navy's N-ROSS satellite planned for launch in 1988. Thus, the combination of TOPEX and N-ROSS will provide the necessary satellite-derived data for studying ocean circulation.

Sensors

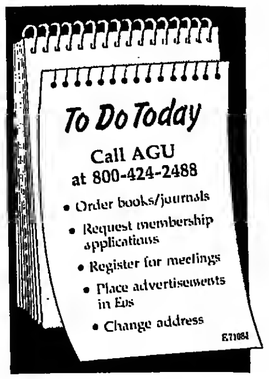
TOPEX will carry a dual-frequency altimeter to measure the satellite-to-sea surface range. The primary measurement frequency is 13.7 GHz (Seasat used 13.5 GHz), and the second frequency is 5.3 GHz. The range difference measured at these frequencies provides a first-order correction for the influence of the ionosphere. A three-frequency microwave radiometer (18, 21, and 37 GHz) will provide a correction to the altimeter height measurement for the effects of atmospheric water vapor. An array of laser retroreflectors onboard the spacecraft will allow independent height measurements to be made from an island calibration site to verify and calibrate the altimeter height measurement. The laser site will be tied by survey to local mean sea level and tide gauges around the island will measure local variations in sea level at the time of satellite overflight. The satellite will directly overfly the laser site, thereby allowing an independent measurement of the satellite height. In addition, one or two buoys will be located offshore along the satellite ground track in order to verify the altimeter's measurement of wave height and wind speed.

The prime instrument for precise tracking of the spacecraft is a Doppler beacon to be used with the Defense Mapping Agency's Tranet Tracking System. Also, payload capacity has been reserved for a high-precision radiometric tracking system to be carried as an experiment. The experimental system probably will be a receiver which extracts pseudo range (range plus a clock bias) from the transmissions of the Global Positioning System (GPS) satellites. Pseudo range from four or more GPS spacecraft can be combined to determine receiver position and receiver clock bias. If pseudo ranges to a ground receiver and a receiver onboard TOPEX are measured simultaneously from two GPS spacecraft, these range measurements can be doubly differenced, thereby eliminating all clock errors. By using double differenced range measurements from the anticipated 18-satellite operational GPS constellation and seven or eight ground stations, it should be possible to determine global orbits for TOPEX to subdecimeter accuracy.

Data Products

The TOPEX mission will produce both environmental and research data. Environmental data, which will be supplied to Navy's Fleet Numerical Oceanographic Center within 4 hours of receipt, include wind magnitude and measurements of wave height. The primary data for research will be height data corrected for instrument, atmosphere, and surface effects, as well as measurements of wave height and wind magnitude. Additional information to be supplied on the science data record includes the precise position of the spacecraft and the geoidal and tidal height at the satellite nadir point based on the best available models. Also, range difference between the two altimeter frequencies (proportional to total columnar electron content) and columnar water vapor content from the radiometer will be provided.

The initial 6-month period following launch will be used to assess the performance of the satellite and verify the accuracy of the satellite measurements and the ground processing system and associated data products. The TOPEX data system will be a dedicated central processing facility and will be in place and operational 6 months prior to launch. Routine production of science data records will begin about 6 months after launch, and the system will be configured to process 24 hours of TOPEX data in approximately 6 hours. Data will be distributed to science investigators via an ocean data system at the Jet Propulsion Laboratory or by the National Environmental Satellite Data Information Service of the National Oceanic and Atmospheric Administration.



Orbit

Current plans are to place the TOPEX satellite in a circular orbit inclined at 63.4° to the equator at an altitude of 1334 km. This baseline orbit was chosen because (1) it avoids aliasing tidal signals into annual and semi-annual frequencies, (2) the inclination is such that the orbit covers the southern limit of the Drake Passage and still provides reasonable crossing angles between ascending and descending orbital arcs for the recovery of both zonal and meridional components of topography, and (3) the altitude is high enough to mitigate the effects of atmospheric drag and gravitational perturbations on the orbit, thereby allowing a more accurate determination of the orbital height. The orbit will be controlled to exactly repeat (to within ±1 km) every 127 revolutions or about 10 days resulting in spacing between equatorial tracks of 315 km (Figure 3). The repeat period was chosen as a compromise between the desire to obtain both high temporal and high spatial resolution.

One of the major challenges facing the TOPEX mission will be the determination of the altitude ephemeris of the satellite. As seen from Table 1, uncertainty in knowledge of the height of the orbit is the major contributor to the error budget. Knowledge of the spacecraft position is required to separate variations in the altimetric range measurement due to the satellite motion from those caused by elevation changes in the ocean surface.

During the Seasat program, impressive progress was made in the ability to reconstruct the satellite trajectory using laser and radiometric tracking data (Figure 4). However, considerable improvement in knowledge of the longer wavelength (>1000 km) components of the earth's gravity field is necessary in order to reconstruct the TOPEX radial ephemeris to the required accuracy. A 4-year program was initiated in FY84 (Fiscal Year 1984) by NASA to produce a gravity field improved at spacecraft altitude by at least a factor of 2 over the current best unclassified models. This field will be derived by using much more of the available satellite tracking data than has previously been used for gravity recovery. The improved gravity field together with global tracking by the Tranet system will allow the TOPEX orbit to be determined with decimeter accuracy.

Present Status

TOPEX is managed by the Jet Propulsion Laboratory for NASA and is currently a development flight project. This means that it does not yet have a project start; however, it is a strong candidate for an FY86 project start which would allow a launch in 1989.

The Goddard Space Flight Center has a substantial role in TOPEX and is responsible for supplying the two-frequency altimeter and precise orbits for distribution with the altimeter data. The altimeter will be built by the Applied Physics Laboratory of Johns Hopkins University. The Center for Space Research at the University of Texas at Austin will participate in and be responsible for certain activities associated with verifying the accuracy of geophysical data products and precise orbits. Present plans call for the Defense Mapping Agency to provide globally distributed Tranet tracking data; the Fleet Numerical Oceanographic Center to provide atmospheric pressure, temperature, and water vapor fields; and for the National Oceanic and Atmospheric Administration to provide the necessary in-water observation data to verify the altimeter geophysical data products, height, wave height, and windspeed.

A Science Working Group has been established to provide scientific guidance in designing the mission. A Precision Orbit Determination Task Group has been formed to advise the project on matters related to tracking and orbit determination of the satellite.

The mission has been under study since 1980, and significant progress has been made on minimizing cost with little compromise of data accuracy. During FY84, three industrial firms will study the possibility of using off-the-shelf satellite configurations to carry the TOPEX sensors. In addition, the production of an altimeter development model was initiated in FY83 at the Applied Physics Laboratory. An "announcement of opportunity" soliciting proposals to do scientific research with the TOPEX data is planned for release by NASA Headquarters early 1985.

A study is currently underway with the French Centre Nationale d'Etudes Spatiale regarding the possibility of a joint (U.S./French) TOPEX-Poseidon altimetric mission. Under current proposals, the French would launch the TOPEX satellite into orbit with the Ariane booster. The TOPEX payload would be increased to include two French sensors, a high-precision Doppler tracking system (DORIS), and an altimeter sharing the TOPEX altimeter antenna. There would be collaboration between U.S. and French scientists in the areas of data evaluation, precision orbit determination, and scientific applications of the data. NASA also is proceeding with the definition of a shuttle-based U.S. mission as a backup to the U.S./French joint mission.

Suggested Reading

A comprehensive discussion of the science objective and requirements for the TOPEX mission is given by the TOPEX Science Working Group in "Satellite Altimetric Measurements of the Ocean," *JPL Doc. 400–111*, Jet Propulsion Laboratory, Pasadena, Calif., March 1981.

Several survey articles have recently appeared that have extensive bibliographies and describe progress made in the application of altimetry to geodetic and oceanographic problems: (1) J. G. Marsh, Satellite altimetry, *Rev. Geophys. Space Phys., 21*, 574–580, April 1983; (2) O. Brown and R. E. Cheney, Advances in satellite oceanography, *Rev. Geophys. Space Phys., 21* 1216–1230, April 1983; and 13) L. L. Fu, Recent progress in the application of satellite altimetry to observing the mesoscale variability and general circulation of the oceans, *Rev. Geophys. Space Phys., 21* 1657–1660, November 1983. In addition, a special of *Marine Geodesy* (vol. 8, April 1984) dedicated to satellite altimetry will be published early in 1984.

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George H. Born *received a Ph.D. in aerospace engineering from The University of Texas at Austin. For the past year, he has been a Senior Research Engineer at the University of Texas Center for Space Research. Prior to this, he was involved with satellite navigation for Planetary Programs at the Jet Propulsion Laboratory, and he also served as Geophysical Evaluation Manager and coordinated precision orbit determination activities for the Seasat project at JPL.*

Charles A. Yamarone, Jr., *manages the TOPEX development flight project at the Jet Propulsion Laboratory. Previously, he managed information processing for Seasat and the Seasat Data Utilization Project. Prior to his Seasat assignment he was a technical section manager for the development of ground data systems for most of JPL's planetary programs.*

News

Shuttle Mission To Study Halley

A series of astronomy missions slated to be carried aboard the space shuttle will lead with a special look at Halley's Comet.

The missions, dubbed Astro, consist of three ultraviolet telescopes that will be used to study stars and galaxies. To study Halley's Comet, a pair of visible-light cameras have been added to the Astro payload's first flight, scheduled for March 1986.

Astro's three telescopes are the Hopkins Ultraviolet Telescope, the Wisconsin Ultraviolet Spectropolarimeter, and the Goddard Ultraviolet Imaging Telescope. These telescopes are aligned for simultaneous ultraviolet imaging and for taking simultaneous spectroscopic and polarization measurements of astronomical objects, including Halley's Comet.

The first 7-day Astro mission, scheduled at a time when several comet probes will intercept Halley, will return scientific data on and photography of the comet. The European Space Agency, Japan, and the Soviet Union have each designed probes to fly by the comet and through its tail in early March 1986.

The National Aeronautics and Space Administration (NASA) has selected eight scientists, who, together with three other scientists each representing one of the three telescope teams, will form the Astro Halley Science Team. The team has been charged with planning the overall program for observing the comet.

The eight scientists selected by NASA for the Astro Halley Science Team are Michael A'Hearn, University of Maryland, College Park; John Brandt, Bertram Donn, and Malcolm Niedner, of NASA's Goddard Space Flight Center; Barry Lutz, of the Lowell Observatory in Flagstaff, Ariz.; Chet Opal, at the University of Texas, Austin; C. Robert O'Dell, of Rice University; and Susan Wyckoff, of Arizona State University in Tempe.

In addition, NASA recently announced its selection of three scientists to train as payload specialists for Astro. They are Samuel T. Durrance of The Johns Hopkins University, Kenneth H. Nordsieck of the University of Wisconsin-Madison, and Ronald A. Prise of Computer Sciences Corp., of Silver Spring, Md.

The Astro mission is being managed by the Marshall Space Flight Center. The observatory is scheduled for assembly and integration into the space shuttle at Kennedy Space Center during 1985. Astro missions will use a pair of Spacelab pallets and the Spacelab instrument pointing system.

Geodynamics Study in Israel

The origin of Mediterranean earthquakes and the precise determination of very small movements of the earth's crust will be the focus of a joint study by the Israeli Space Agency and the National Aeronautics and Space Administration (NASA). Israel will join 11 other countries conducting laser ranging activities with NASA as part of the agency's geodynamics program.

As part of a global network striving for determining with a precision of 3 cm small movements in the earth's crust, the Israeli Space Agency will build a ground station that will beam low-power laser pulses to several satellites, including LAGEOS (the Laser Geodynamics satellite) and the French satellite Starlette. NASA's annual budget for the global network is roughly $30 million.

Israel's fixed station will also work with mobile laser tracking stations to map regional patterns of crustal deformation and to monitor strain accumulation. The station is expected to begin measuring crustal movements under the international program in 1985. Other countries in Europe and North Africa—including France, the United Kingdom, the Federal Republic of Germany, the Netherlands, Sweden, Switzerland, and Italy—are involved in the cooperative research program.

The system to be installed in Israel was built and operated by the Smithsonian Institution. About 2 years ago it was moved from Australia to the United States for refurbishment. Later this year a site will be selected in Israel and the system will be shipped.

Mount Wilson Telescope to be Mothballed

As part of its plan to direct resources to its astronomical research facilities in Chile, the Carnegie Institution of Washington will mothball the Mount Wilson 2.54-m telescope on July 1, 1985, and will gradually decrease support for the 45.7-m and 18.3-m solar tower telescopes. Concurrently, the Mount Wilson and Las Campanas Observatories' technical development group in Pasadena, Calif., will be expanded.

New equipment will be acquired for the Las Campanas Observatory in Chile, where Carnegie operates two modern telescopes. A charged coupled device camera will be added to the 1.0-m telescope at the observatory to yield more accurate imaging of extremely faint objects. Another charged coupled device will enable the recording of spectra of extended sources, including galaxies and emitting clouds. Eventually, this device will permit fiber-optical feeds for the simultaneous recording of many objects in a group of stars or galaxies. Also on the list is a new spectrograph that will introduce high-resolution spectroscopy for the first time at the Las Campanas Observatory's 2.54-m telescope. Computer facilities at the observatory will be upgraded. In addition, improvements will be made for the television viewing systems that aid in locating faint sources in the telescope field of view.

The search is on for a new operator for the Mount Wilson telescopes. Solar-stellar physicists may find the site ideal. George W. Preston, director of the observatories reportedly is optimistic that suitable management for the Mount Wilson facilities will be found.

Carnegie operates five research centers: the Mount Wilson and Las Campanas Observatories (with offices in California), the Department of Plant Biology in Stanford, Calif., the Department of Embryology in Baltimore, Md., and the Department of Terrestrial Magnetism and the Geophysical Laboratory, both located in Washington, D.C.

Upcoming Hearings in Congress

The following hearings and markups have been tentatively scheduled for the coming weeks by the Senate and House of Representatives. Dates and times should be verified with the committee or subcommittee holding the hearing or markup; all offices on Capitol Hill may be reached by telephoning 202-224-3121. For guidelines on contacting a member of Congress, see *AGU's Guide to Legislative Information and Contacts* (*Eos*, April 17, 1984, p. 159).

July 11 and 12: Hearing on the effects of nuclear war by the International Trade, Finance, and Security Economics Subcommittee of the Joint Economic Committee. July 11, Dirksen Senate Office Building, Room SD-628, 10 A.M. July 12, Dirksen Senate Office Building, Room SD-138, 10 A.M.

August 6: Hearings on the contracting of National Oceanic and Atmospheric Administration mapping and charting services by the National Ocean Policy Study Subcommittee of the Senate Commerce, Science, and Transportation Committee. Russell Senate Office Building, Room SR-253, 10 A.M.

TBA: Conference committee on legislation for ocean and coastal resources block grants for fisheries programs and deep seabed hard minerals resources programs. Time, date, and location to be announced. Senate conferees: Packwood (R-Oreg.), Stevens (R-Alaska), Gorton (R-Wash.), Hollings (D-S.C.), and Inouye (D-Hawaii). House conferees: Jones (D-N.C.), Breaux (D-La.), Studds (D-Mass.), D'Amours (D-N.H.), Pritchard (R-Wash.), Young (R-Alaska), and Carney (R-N.Y.).
— BTR

EOS
Transactions, American Geophysical Union
The Weekly Newspaper of Geophysics

For speediest treatment of contributions send three copies of the double-spaced manuscript to one of the editors named below and one copy to AGU.

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Subscription price to members is included in annual dues ($20 per year). Information on institutional subscriptions is available on request. Second-class postage paid at Washington, D. C., and at additional mailing offices. *Eos, Transactions, American Geophysical Union* (ISSN 0096–3941) is published weekly by

American Geophysical Union
2000 Florida Avenue, N.W.
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Cover. A rendition of the ocean topography satellite, TOPEX, viewing the North Atlantic Ocean. The left-most panel is an example of the inference of ocean bathymetry from its surface expression as measured by the Seasat altimeter (courtesy of W. Haxby, Lamont-Doherty Geological Observatory). Notice the detail of such features as ocean trenches, seamounts, and the continental shelf. These features are detectable because the shape of the ocean surface closely conforms to the gravitational anomalies associated with them. The bottom panel illustrates the use of Seasat altimetry for the determination of mesoscale oceanic variability (courtesy of R. Cheney, NOAA, and J. Marsh, NASA). Red areas off the east coast of the United States are regions of highest variability associated with the Gulf Stream. (Cover design by InterNetwork, Inc.) (See article by Born et al. this issue.)

Classified

Chief of Telescope Operations/Haystack Observatory. Haystack Observatory has need for a Chief of Telescope Operations, who will be responsible for scheduling and coordinating astronomical observations using the Haystack 120-foot and 60-foot radio telescopes. The primary duties will be training and supervising telescope operators, scheduling antenna use for astronomy, maintenance, and other activities, and interfacing with investigators to assure the success of their observations. The person will also be the system manager of the HP1000 computers used to control the telescopes and data acquisition hardware; some experience in FORTRAN is required for maintenance of the existing software. In addition, participation in the evaluation of the feasibility and merit of proposals to use the telescopes for astronomical observations will be required; thus, the successful candidate is expected to have some knowledge of astronomy. Since successful observing depends on proper use of equipment, some experience with the use of instrumentation for scientific data collection is highly desirable. A negotiable fraction of time will be available for research and participation in software or instrumentation development, depending on the qualifications and interests of the applicant. We seek an individual with supervisory and organizational skills who is interested in a long-term commitment to furthering the progress of astronomical research. Haystack Observatory is operated by the Massachusetts Institute of Technology for the Northeast Radio Observatory Corporation, a consortium of Northeast institutions. It is located 40 miles northwest of Boston in a rural environment, with easy access both to city activities and to the coastline and mountains of New England.

Please write, enclosing resume to:
J. T. Karaku
Assistant to the Director
Haystack Observatory
Westford, MA 01886

MIT is an equal opportunity/affirmative action employer.

Faculty Position In Atmospheric Sciences/North Carolina State University. A tenure track nine-month position is available at the Assistant/starting Associate Professor level beginning January 1985. The appointee must have completed all requirements for the Ph.D. degree and should have a strong background in dynamical meteorology. Special consideration will be given to candidates whose research emphasizes *mesoscale phenomena* and processes. An opportunity exists to participate in the recently initiated GALE program. The appointee will be expected to teach courses at both the undergraduate and graduate levels. The appointee would join the Marine, Earth and Atmospheric Sciences Department, which consists of 9 meteorologists, 11 geologists and 11 marine science faculty. The Department enjoys well-established and mutually-beneficial relationships with the related programs at the University of North Carolina at Chapel Hill, Duke University and institutions in the nearby Research Triangle Park. Applicants should submit a resume, and the names and addresses of three references to Dr. S.P.S. Arya, Chairman, Search Committee, Department of Marine, Earth and Atmospheric Science, North Carolina State University, Box 8208, Raleigh, NC 27695–8208; 919-737-2210. Consideration of applicants will begin on September 1, 1984. North Carolina State University is an Affirmative Action/Equal Opportunity Employer.

Research Associate/Research Technician. The University of Maine at Orono (UMO) has an opening for a research associate/research technician who would work in a small geophysical group. We seek an individual who can use and maintain modern digital electronic equipment; for example, multi-channel analysers, I/O interfaces for microcomputers, digital plotters and digitizing tablets. Familiarity with BASIC and FORTRAN will be needed, and some geophysical field work may be required as part of the duties of the appointee. Current funding permits an appointment for at least 12 months. Subject to arrival of anticipated funding, the appointment period could be extended to two years or longer. Call Edward R. Decker at 207-581-2158 or 207-581-2152 about the position. Otherwise, send inquiries, a vita and a list of at least three references to Edward R. Deckee, Department of Geological Sciences, 110 Boardman Hall, University of Maine at Orono, Orono, ME 04469.

The University of Maine is an equal opportunity/affirmative action employer.

Research Assistant Professor/Shallow Water Simulation. A two-year, non-tenure track appointment is available at Dartmouth College. Primary emphasis is on research in hydrodynamic and water quality simulation for estuaries, lakes, and coastal waters. The position also involves teaching one course per year. Additional opportunities exist for involvement in Geophysics, Numerical Methods, or Cold Regions programs.

Applicants must hold the Ph.D. in any relevant scientific discipline. Ability with finite elements and/or boundary elements is strongly favored.

Desired start date is October 1, 1984. Renewal of initial appointment is possible, contingent upon generation of additional research funding. Send resume with three references and dissertation abstract by August 15 to:

Professor Daniel R. Lynch
Thayer School of Engineering
Dartmouth College
Hanover, New Hampshire 03755

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Area Geophysicist. M.S. in geophysics required with two years experience as seismologist and/or geologist to evaluate state-of-the-art geophysical software and determine that software employs current and accepted theories of geophysics; some programming required to implement new geophysical concepts developed by the hiring company; will participate in the formulation of new processes of vertical seismic profiles, three-dimensional processing and well-log processing; require proven research abilities; salary $33,200 per year; forty hour week; send resume to the Job Service Center, 8585 W. 14th Avenue, Lakewood, CO 80215, referring to Job Order# 2481345.

Senior Research Scientist. Senior Research Scientist, Applied Science Associates, Inc. (ASA) a consulting ocean engineering and sciences firm specializing in numerical modeling of shelf, coastal and nearshore processes, is seeking to add senior level positions to its rapidly growing staff. Applicants with research interests in numerical modeling of oil spill fates and impact, nonlinear dynamics, marine and groundwater hydrodynamics and pollutant transport, sediment transport, and wave dynamics are of particular interest. Applicants should submit a resume, evidence of the ability to generate a contract-supported research program, and the names of three references to:

Dr. Malcolm L. Spaulding
Applied Science Associates, Inc.
208 Main Street
Wakefield, Rhode Island 02879.

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AGU

1984 Robert E. Horton Medal to Charles V. Theis

Citation

It is indeed a privilege to present the Horton Medal to one of my colleagues at the U.S. Geological Survey (USGS), C. V. Theis. Theis' contributions to groundwater hydrology over an active lifetime of inquiry have helped shape and reshape the science as we now know it. Certainly others may have accumulated a greater number of publications, but no one person has had a greater impact on groundwater hydrology in the past 50 years than C. V. Theis.

Theis was born in Newport, Kentucky, in 1900, and he received a bachelor's degree in civil engineering from the University of Cincinnati in 1922; in 1929 he received the first Ph.D. degree in geology granted by Cincinnati. His thesis was entitled "Geology of Henderson County, Kentucky." It seems remarkably fitting that we are gathered in Cincinnati half a century later to make this presentation. In 1930 he joined the staff of the USGS as an Assistant Geologist in the Water Resources Division; it was in that position he became associated with O. E. Meinzer. In 1931, Theis was assigned to do a quantitative investigation of the groundwater resources of Portales Valley, N. M., an area in the High Plains. After several successive investigations of groundwater in the High Plains, he was assigned in 1934 to head the Public Works Administration study of the Southern High Plains, from Kansas south.

In considering the effects of groundwater pumping in the High Plains, Theis stated: "It was evident that the current equilibrium treatment would not suffice." In 1935, Theis published in the *Transactions of the American Geophysical Union (Eos)* the paper entitled "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage": it was this paper that laid the foundation upon which most of groundwater hydrology since has been built.

The hydrologic community is aware of C.V.'s classic 1935 paper, which provided the foundations for what we now refer to as the "Theis Equation." Perhaps not so well understood is how this development ushered in a whole new era of quantitative groundwater hydrology. A brief historical view may place this contribution in its proper perspective.

There was a long hiatus between the pioneering work of Darcy in 1856 and the theoretical work by Thiem and Slichter at the turn of the century. The theory as known at that time allowed for quantitative analysis of steady state, equilibrium, flow. In the 1920's, Meinzer, Thompson, and others gradually became aware that steady state was not adequate; however, it was Theis in 1935 who provided the essential idea. The science of groundwater immediately began to take on a new form and has continued to evolve for nearly 50 years. Much of the credit for this growth goes to Theis for several rather specific reasons:

The first and perhaps most important reason is philosophical. Theis obviously influenced his colleagues, many of whom were classical geologists, to think of hydrologic phenomena in a manner that was not fashionable at the time. He introduced the concept that the study of hydrogeology could be facilitated by the use of analytical models which describe or explain physical phenomena. At that stage, hydrogeology began to mature as science. Because he introduced and contributed to this perspective, many hydrologists rank Theis with other giants of his era: Karl Terzaghi in soil mechanics, Forchheimer in applied hydraulics, and Theis' good friend, M. King Hubbert, in hydrodynamics.

A second reason relates more to the scientific impact of C. V. Theis' contributions. Clearly, C. E. Jacob's derivation for the flow of water in elastic aquifers, published in 1940, was motivated by Theis' work. This follows naturally from the fact that Jacob's theory, which leads to Theis' solution for a prescribed set of initial and boundary conditions, was derived after the solution itself was known. This demonstrates to me that Theis' reasoning was more heuristic than obvious; it is this kind of intellectual thought that has led to the truly original ideas in science. Later contributions in well hydraulics, mainly by Jacob, Hantush, and others, built on Theis' original work. Further, the concept of storativity introduced by Theis has found widespread application; it implies that rock bodies are not rigid but are indeed compressible. This has led to a clearer understanding of the manner in which wells and aquifers respond to various forces, such as atmospheric and earth-tide loading.

The period 1935 to about 1962 was a golden era in transient groundwater hydrology, and Theis' original work was the basis of almost all of the scientific information accumulated over that period.

In addition to his direct contributions to science, C. V. Theis has had a distinguished career as a technical manager and teacher. During World War II he was in charge of the water supply work of the Military Geology Section of the USGS. He was the first district geologist in New Mexico, appointed in that position in 1939, a position he held until 1951. In 1951 he was appointed coordinator for water disposal in the Atomic Energy Commission by the USGS. He has since served on several National Research Council committees dealing with radioactive waste disposal. In 1961 he taught at Columbia University as an adjunct professor; in 1962 he was appointed research associate in geology at the University of New Mexico. Although retired in 1970 he has worked for the USGS on a WAE basis since; he continues to live in Albuquerque and comes regularly to the office where he has worked since 1936.

I am one of the group of younger generation hydrologists at USGS who have had the opportunity to be associated with C.V. as a colleague. Through the 5 decades that he has been active at USGS, many of us have had this privilege. To a man, all of C.V.'s colleagues would stand and testify to the impact he has had in their thinking and development as scientists. All of us who know him hold C.V. in the highest esteem. On behalf of the American Geophysical Union, it is with great personal pleasure that I present the Horton Medal to C. V. Theis.

John D. Bredehoeft

Acceptance

Thank you, President Van Allen; thank you, John Bredehoeft, for your kind words; and thank you, Allen Freeze, and your committee, and the members of AGU in general, for choosing me for this honor. Later, I shall indicate why I am particularly pleased to receive the Horton Medal.

Of course, no man stands alone. When I introduced the transient theory, I encountered some opposition in the groundwater part of the U.S. Geological Survey (USGS), beginning with my boss, O. E. Meinzer. So I must thank the late C. E. Jacob for his work in further explanation of the transient theory and his pupil, the late Mahdi Hantush, who developed the theory in great detail and extended it to about every geometry of homogeneous aquifer that is possible to conceive.

And I must also thank John Bredehoeft and his cohorts, Hilton Cooper and Steve Papadopulos, for lately calling the attention of the computer generation to the fact that the discharge of a well or wells can be balanced only by decreasing the natural discharge or increasing the recharge of the groundwater body. Their paper has saved me from polishing up a draft lying on my desk.

Inasmuch as I am probably the only recipient of the Horton Medal, past or future, who knew Robert Horton personally, I wish to recall some of the characteristics of the man and some of my relationship with him. This award of the Horton Medal comes at about the close of my scientific career; Robert E. Horton himself helped me begin my hydrological career. I have a great deal for which to thank Robert E. Horton.

After receiving my advanced degree, I spent a year with the Corps of Engineers in Cincinnati, and then joined the Division of Ground Water (as it was then called) of the U.S. Geological Survey, under O. E. Meinzer. I first met Meinzer late in 1930. In the spring of 1931, Meinzer was very busy as the chairman of a committee to form a Section of Hydrology in the AGU. Robert Horton was vice chairman of this committee. The result of their effort was the first meeting of the Section of Hydrology in connection with the 12th annual meeting of the AGU itself.

Meinzer asked several members of his Ground Water Division to prepare review papers for this first program of the Section of Hydrology. While I was working with the Corps of Engineers, I became interested in reservoir evaporation, among other things, and, as a start, I tried to develop on my own time a relationship between monthly values of evaporation from a standard pan and monthly values of insolation, vapor pressure deficit, and wind movement.

I got a fairly good correlation for the places and years for which data were available. So when Meinzer asked me to give a review paper on evaporation, I included my own work. Meinzer did not like this. However, the meetings were imminent, and so my own work remained in the paper. At the end of the meeting, Horton came forward and said to me, "You might have been in my office! I used about the same data as you did, but you got a lot closer correlation than I did." This was in Meinzer's hearing. The next week, he came into my office and said, "It seems that I misjudged your work." Hence, Robert E. Horton was the first man to compliment work of mine after I joined the USGS. And incidentally, this occurrence indicated the utter honesty of O. E. Meinzer.

Oscar E. Meinzer (1876–1948) and Robert E. Horton (1875–1945) were almost exact contemporaries. Both were great hydrologists; Horton was primarily interested in surface water and Meinzer, of course, in groundwater.

However, there were other great differences between the two men. Meinzer did quantitative work of an arithmetic nature in his early field studies, but his great work was the organization of the contributions of men in various sciences and focusing them on the study of groundwater. Meinzer could also digest the work of many geologists and recapitulate it. This was a great gift.

Horton took the raw data from hydrology and tried to establish a quantitative relation between them, empirical, if need be. He described his outlook in his paper in this same first meeting of the Section of Hydrology: "The Field, Scope, and Status of the Science of Hydrology." He synthesized the quantitative studies of himself and others with regard to surface streams in his last contribution, published in the *Bulletin of the Geological Society of America*: "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology." I received from Horton a separate copy of this paper, with a request for comments, a few days after his death.

John Bredehoeft has given some dates regarding the theory of transient groundwater flow. I myself am struck by how the theory of groundwater movement has advanced by pulses. In the 6th decade of the last century, Darcy found, by careful experiment, the nature of flow through filter sands, but apparently refused to apply his "law" to natural artesian flows. Dupuit, in the same decade, extended groundwater study by making the grand assumption that natural water-bearing formations were uniform and amenable to the same law. I have often wondered if Darcy may have looked at mere sandstones then Dupuit. Near the turn of the century, Slichter in this country and Forchheimer in Austria were doing their theoretical work, and Gunther Thiem was applying Dupuit's work to groundwater exploration. At least in this country, the fourth decade of this century was the most active in regard to the advance of quantitative geohydrology. Wenzel was making his elaborate test of Theim's method in Nebraska and other tests elsewhere; my papers on the transient cone of depression were published in 1935, 1938, and 1940. Tolman's "Ground Water" and Muskat's "Flow of Homogeneous Fluids Through Porous Media" were both published in 1937. Finally, King Hubbert's "The Theory of Groundwater Motion" capped the decade, in more ways than one, in December 1940.

Finally, I must tell John Bredehoeft that a young fellow who thought more or less like Horton, and had O. E. Meinzer as a boss, had some difficulty in getting his ideas across. Meinzer certainly had no conception of the need for a transient theory of the cone of depression around a discharging well. My first paper on the transient cone included a corollary giving a method of computing transmissivity from the recovery of water level after discharging a well. Meinzer told me I'd years or so after publishing this that my "so-called corollary" would prove to be the only valuable part of my equation. Some time before, he told me that he didn't like my "deductive thinking." David Thompson had been bothered for years by the hysteresis loops he had observed in the water levels near the pumping wells at Atlantic City, and he probably did believe in some sort of transient theory. He was very happy when I sat in his office one day, and after he had made some generalizations about the nature of the aquifer and some estimates of seasonal pumping, I gave him slide-rule figures that showed the same hysteresis loops.

However, I must hasten to add that a few years later, and after C. E. Jacob had been in the Washington office a little while, Meinzer *could* commend in print my "pioneering" work on the transient theory and later would ask me to write the quantitative chapters of the text on groundwater he had started to write at the time of his death. I was much more fortunate in this respect than King Hubbert, whose ideas about movement of groundwater, much more revolutionary at the time than mine, had even more difficulty in becoming accepted generally.

In trying to recall the events that occurred during Robert Horton's years, little time is left to talk about the facets of groundwater science that occurred after the effects shown by tracers and contaminants forced the study of transport in groundwater and forced a re-evaluation of the natural medium in which groundwater occurs and in ways of dealing with the new phenomena.

We should note, I think, that the study of the transport of solutes in groundwater flow repeated the beginning of the first study of groundwater movement. In the last century, Darcy studied flow through porous media in the laboratory. Dupuit assumed without any proof that Darcy's law could be applied to natural groundwater systems. In the study of transport, work was also begun in the laboratory by students of Harold A. Thomas at Harvard (a former recipient of the Horton Medal) and students of David Todd and the late Warren Kaufman at Berkeley, Calif. However, when the latter investigators turned to the field, they and contemporary and subsequent investigators found that the field dispersivities were a few to several orders of magnitude greater than those found in the laboratory.

Thus we came full circle from the assumption of homogeneity that had been used for 100 years to the demonstration that heterogeneity characterized all known water-bearing formations.

Perhaps we can recapitulate the history of some of the hydrology we have mentioned here by a couple of quotations from Robert E. Horton. First, from his paper at the first session of the Section of Hydrology: "The shattering of ancient idols of belief by die iconoclastic methods of experimental research has left science chary of accepting as definitive knowledge anything that has not been tested quantitatively and then checked and double-checked." And as a valedictory to end his last published paper: "It is also hoped that the reader will find stimulation to further study and research."

C. V. Theis

AGU Membership Applications

Applications for membership have been received from the following individuals. The letter after the name denotes the proposed primary section affiliation.

31st Pacific Northwest Regional Meeting

September 7-8, 1984
Oregon State University
Corvallis, Oregon

Convenors: Robert A. Duncan & Shaul Levi

Abstract Deadline August 1, 1984

(Call for Papers was Published in Eos, June 12)

For information on the abstract format or other meeting logistics contact:

Meetings Department
American Geophysical Union
2000 Florida Avenue, N. W.
Washington, D. C. 20009
Telephone (202) 462-6903

For program information contact:

Robert Duncan
College of Oceanography
Oregon State University
Corvallis, Oregon 97331
Telephone (503) 754-2296

Regular Members

Andreas Angelakis (H), Trevor F. Baker (G), Jim Barnard (A), Edward Erlich (V), Timothy B. Flagler (T), Long-Sheng Gan (S), Ruth M. Gow (V), Roger L. Hughes (O), Bruce R. Kovac (H), Craig D. Martin (H), S. I. Mohsin (V).

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Ahmet Tevfik Arguden (T), Sharon Bailer (T), Jean-Paul Bouvet (S), Iver Hugh Cairns (SS), DeWayne Cecil (H), Francisco Chavez (O), Carl W. Eberling (V), James L. Evans (O), Stanford Hooker (O), Bruce M. Howe (O), David A. Kellogg (S), Catherine Leser (H), Elizabeth L. Rich (O), Kirk Rundle (S), Susan K. Spence (S), William J. Taylor (S), Frederick J. Tenbus (H), Bertrand L. Theriveny (H), Gary A. Thumen (S), Robert Ward (T), Chong-Kung Wu (O), Andrew Zachary (SS).

Meetings

Session Highlights

Atmospheric Sciences (A)

Chemistry of the Global Atmosphere

Papers are solicited on the processes that control the chemistry of the global atmosphere and the connections between global atmospheric chemistry and climate. Tropospheric topics of special interest are biogenic sources of atmospheric chemicals, tropospheric photochemistry, heterogeneous reactions and removal processes, and long-range transport and global distributions of various species. Contributions are also sought on the atmospheric components of biogeochemical cycles, the relationships between tropospheric and stratospheric chemistry, and climate and relevant experimental research in instrument development and laboratory photochemistry and kinetics.

The coconveners are R. J. Cicerone and R. A. Dare.

There will also be a special half-day session under Chemistry of the Global Atmosphere, titled "The NASA GTE/CITE Project." The convener will be Robert J. McNeal.

Acid Deposition Modeling

In recent years, as the likelihood for regulations on limiting atmospheric releases of acid-forming pollutants increases, considerable attention has been devoted to the current state of knowledge on acid deposition modeling. Theoretical modeling of the physical processes for the transport, transformation, and deposition of acids and acid forming precursors is essential, both for further research and for regulatory applications. In particular, the development of state-of-the-art models is an explicitly recognized critical component of the acid precipitation research programs in the United States, Canada, and the Federal Republic of Germany. The objective of this special session is to provide a forum for the exchange of detailed information on all facets of acid deposition modeling.

Papers are solicited dealing with representations of source functions, plume transport and dispersion, chemical transformation, long-range transport, atmospheric scavenging, numerical techniques, sensitivity and uncertainty analysis, concepts and techniques for *model* validation, and model applications. Every effort will be made to establish a balanced program with contributions from empirical, Lagrangian, Eulerian, and statistical approaches to acid deposition modeling. The contents of these sessions will focus upon the complexity, successes, and failures in modeling individual physical processes, as well as the overall integrated regional acid deposition models and long-range transport models. Papers on the role of nonlinear chemistry or contrasting linear and nonlinear chemical representations are especially welcome. Selected overview and a few papers of general interest will be invited.

Please mail the original plus two copies of your abstract, in standard format, to AGU and one copy to the convener, Julius S. Chang, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307 (telephone: 303-497-1680 or 303-497-1681) by the September 12 abstract deadline.

Mesoscale Convective Systems and the STORM Program

Convective systems which span the mesoscale and interact with the larger synoptic scale flows dominate our nation's significant weather. The national STORM program is a national community effort to marshall the resources necessary to effectively study this weather and to improve forecasts. STORM will focus, in separate years, on the unique weather problems of the central, eastern, and western United States. In addition to documentation of significant weather and its precursors, STORM contains a parallel track in which new forecast concepts will be implemented in real time with the special observations provided by STORM. Contributions to this session are solicited which deal with the observation or theory surrounding mesoscale convective systems, rapid coastal cyclogenesis and rain bands, and other significant mesoscale weather. Contributions may represent case studies, theoretical analysis of these systems, their component parts, or their interaction with larger scale flows.

The convener will be Peter S. Ray.

El Niño, The Southern Oscillation, and the TOGA Program

This session will be an interdisciplinary discussion of El Niño and the Southern Oscillation, as they are presently understood, with emphasis on how new knowledge might affect the evolving design of the TOGA (Tropical Ocean Global Atmosphere) program. Papers will include atmospheric and oceanographic analyses, as well as model results and hindcasts of recent events. Contributions that address the much-studied 1982–1983 event in light of the historical record will be solicited. Papers displaying particular motivation and focus in the design of an effective observational program for TOGA worldwide will be encouraged. Scientific discussion of interannual climate variability as it is (or may be) affected by Atlantic Ocean phenomena are of particular interest, as well as those aimed at the Indo-Pacific region.

The convener is J. Michael Hall.

Hydrology (H)

Isotope Techniques in Groundwater Tracing and Age Dating

There is currently an expanding need for quantitative definition of groundwater flow paths, travel times, paleohydrologic conditions, and related long-term aspects of groundwater flow systems. Much of this need has been prompted by regulatory requirements for high-level nuclear waste repositories, toxic waste disposal sites, and groundwater contamination problems. Additional interest is associated with studies of mineral deposits, paleohydrology, and long-term water resource planning.

Research activities in recent years have produced significant advances in the technology of radio- and stable-isotopic techniques for tracing and dating groundwater. Developments have occurred in standard techniques (such as carbon 14) as well as new methods (such as chlorine 36, uranium series, and others).

A special half-day technical session on this subject is being sponsored by the Groundwater Committee of the Hydrology Section and the Volcanology, Geochemistry, and Petrology Section for the annual fall meeting of the American Geophysical Union in San Francisco, Calif., on December 3–7, 1984. This session will emphasize new developments and field applications of these methods and will include both invited and contributed papers. Abstracts, in standard AGU format, should be sent to Hans C. Claassen, U.S. Geological Survey, Water Resources Division, Mail Stop 415, Box 25046, Denver Federal Center, Lakewood, CO 80225 (telephone: 303-234-2115; FTS-234-2115) by August 15, the special session deadline. In addition, the original and two copies should be sent to Fall Meeting, American Geophysical Union, 2000 Florida Avenue, N.W., Washington, DC 20009, by the September 12 abstract deadline.

Solar and Interplanetary Physics (SS)

SMM-2 is going to emphasize solar-terrestrial relations, and new results are already in hand. B. Woodgate will give an overview of SMM repair and science, followed by invited papers from each experiment team. There will also be an associated special poster session on SMM and related results, especially those with interesting images and visuals. This session is organized by S. T. Suess.

Announcements

Chapman Conference On Solar Wind–Magnetosphere Coupling

Call For Papers

A Chapman Conference on Solar Wind-Magnetosphere Coupling will be held at the California Institute of Technology, Jet Propulsion Laboratory, on February 12–15, 1985. A major goal of solar terrestrial physics is to understand how the solar wind transfers energy to the magnetosphere and the degree to which the interplanetary plasma and magnetic fields control internal magnetospheric processes. The late 1970's and early 1980's produced many new observational data sets and theoretical tools for investigating these issues. In particular, the recent IMP, ISEE, DE, GEOS, and DMSP missions and ground-based measurements in conjunction with the International Magnetospheric Study and NASA Solar Terrestrial Theory Program have made important contributions to our picture of how the magnetosphere interacts with the solar wind and channels energy to lower altitudes.

The purpose of the conference is to focus attention on the solar wind-magnetosphere coupling problem, to provide a timely forum for the exchange of ideas, and to promote interdisciplinary collaboration between the various solar terrestrial investigators and their data sets. Toward this end, the topics to be addressed by the conference will include statistical analyses in solar terrestrial physics, geomagnetic indices and their predictors, response of magnetospheric boundaries, current systems, and plasma to interplanetary conditions, theoretical/experimental coupling functions, and applications of numerical simulation theory.

Format and Abstracts

The conference will last 3 1/2 days and consist of tutorials, invited reviews, contributed papers, and poster talks. Presentations from all points of view on the coupling problem will be encouraged. No parallel sessions are planned. Tours of the JPL spacecraft fabrication, testing, and control/tracking facilities will be available during the course of the conference. Information on plans for a conference proceeding will be available at a later date.

Meetings *(cont. on p. 438)*

Meetings *(cont. from p. 437)*

All who are interested in attending and in receiving later information circulars should write to Solar Wind Meeting, AGU, 2000 Florida Avenue, N.W., Washington, DC 20009 (telephone, toll free: 800-424-2488, or, in the D.C. area, 462-6903). For more information on the scientific program contact the convenors J. A. Slavin, JPL, Caltech, Mail Stop 169/506, 4800 Oak Grove Drive, Pasadena, CA 91109, or Y. Kamide, Kyoto Sangyo University, Kita-Ku, Kyoto 603, Japan.

Abstracts should follow the standard AGU format outlined as published in *Eos*, July 3, 1984. There will be no abstract charge. All abstracts should be sent to Solar Wind Meeting, AGU, 2000 Florida Avenue, N.W., Washington, DC 20009. The abstract deadline is November 1, 1984.

Program Committee: D. N. Baker, Los Alamos National Laboratory; S. W. H. Cowley, Imperial College; D. A. Hardy, Air Force Geophysical Laboratory; Y. Kamide, Kyoto Sangyo University; J. H. King, NASA/Goddard Space Flight Center; L. Lee, University of Alaska; R. L. McPherron, University of California, Los Angeles; P. H. Reiff, Rice University; G. Rostoker, University of Alberta; G. L. Siscoe, University of California, Los Angeles; J. A. Slavin, JPL, Caltech.

Student Travel: Limited funding is available to support student travel expenses. To apply for a travel grant, write or call AGU for a travel grant application form. Deadline for travel applications is October 15, 1984.

Municipal and Industrial Waste

Sept. 10–12, 1984 Seventh Annual Madison Conference of Applied Research on Municipal and Industrial Waste, Madison, Wis. (Philip R. O'Leary, Dept. of Engineering and Applied Science, Univ. of Wisconsin-Extension, 432 North Lake St., Madison, WI 53706; tel.: 608-262-0493.)

The latest developments in land disposal will be featured at the conference, which will be of interest to engineers, geologists, soil scientists, and other specialists involved in the design, operation, and performance evaluation of solid and hazardous waste disposal facilities, industrial and municipal wastewater land application and disposal systems, sludge spreading systems, and other types of application and disposal systems.

Arctic Water Pollution

April 28–May 1, 1985 International Conference on Arctic Water Pollution Research: Applications of Science and Technology, Yellowknife, Northwest Territories, Canada. Organizer: Canadian National Committee, International Association on Water Pollution Research and Control. (K. Charbonneau, National Research Council of Canada, Montreal Road Laboratories, Ottawa K1A OR6, Canada; tel.: 613-993-9009.)

The deadline for submission of abstracts (maximum 250 words) is September 1, 1984.

The conference will provide an opportunity for scientists and engineers to examine the distinction features of water pollution in cold regions, to consider what is known and what are some areas of ignorance concerning the ecological and human health aspects, and to exchange information on monitoring, management, and remedial operations connected with pollution in waters near the freezing point or ice-covered, in permafrost, or in ice masses. The program is tentatively divided into the following sessions: sources, movement, and accumulation of pollutants in the arctic environment; interactions between pollutants and the abiotic arctic environment; effects on arctic biological systems; pollution prevention and control under arctic conditions; and management and information for decisions.

Several field trips are planned during and after the conference.

Meeting Report

1984 Spring Meeting Report

Although attendance was down at the 1984 Spring Meeting, Cincinnati was found to be an ideal site to hold a convention. Final attendance was 1583 with approximately 1100 papers presented.

Changes to the 1984 Spring Meeting program and additional, late, and revised abstracts are printed below.

Papers Not Presented

U12–04, R. J. Cicerone.

A31–08, P. J. Lebel et al.; A41–08, G. W. Adams et al.; A41–09, J. W. Brosnahan et al.; A41–10, S. F. Nerney and G. W. Adams; A42–06, A. W. Hogan et al.; A42–07, M. Reynolds and J. E. Overland.

G41–11, M. A. Slade et al.; G42–09, E. W. Schwiderski.

GD22–11, C. G. Chase and D. R. Sprand; CD41–02, J. C. Negi et al.; GD41–07, C. E. Thobe et al.; GD41–11, S. Hammer and W. R. Gumert.

GP11–04, M. Purucker; GP11–12, M. McWilliams and S. A. Shaver; GP12–08, D. Rankin and F. Pascal; GP21–04, J. C. Liddicoat; GP32–15, D. C. Mishra.

H21A-01, J. E. Houseworth; H21A-10, J. B. Czarnecki; H31B-09, A. D. Gupta; H32–07, G. Padmanabhan and A. R. Rao; H41–05, M. Hauhs and R. R. v. d. Ploeg; H42–15, C. L. Amos.

O21–09, R. Geyer and J. D. Smith; O31A-05, P. Pistek; O32B-05, D. C. Smith.

P11–09, J. Tarney et al.; P22–01, J. A. O'Keefe; P22–03, W. L. Brown et. al.; P22-04, J. B. Garvin.

S11–13, G. H. Sutton et al.; S12–07, F. Tajima.

SA22–01, S. P. Zimmerman and T. J. Keneshea; SA22–05, P. Prikryl et al.

SM11B-02, A. K. Sharma and V. K. Tripathi; SM11B-03, M. McKibben et al.; SM22A-11, C. S. Lin et al.; SM22C-16, J. E. Burovsky; SM22C-17, T. G. Forbes and E. R. Priest; SM41C-19, K. Watanabe et al.; SM42B-12, J. K. Olesen et al.

T22A-01, B. J. Collette et al.; T22A-11, W. R. McCann and R. E. Habermann; T22A-13, O. O. Babalola; T31–10, W. T. Brown; T32A-03, H. P. Johnson et al.; T32A-04, M. Holmes et al.; T32B-10, B. K. Smith.

V31A-05, C. J. Allegre and D. L. Turcotte; V31A-13, J. J. Mahoney; V41A-01, P. R. Vogt and N. C. Smout; V41B-06, C. R. Stern; V42A-01, M. J. Drake et al.; V42B-03, S. V. Raman.

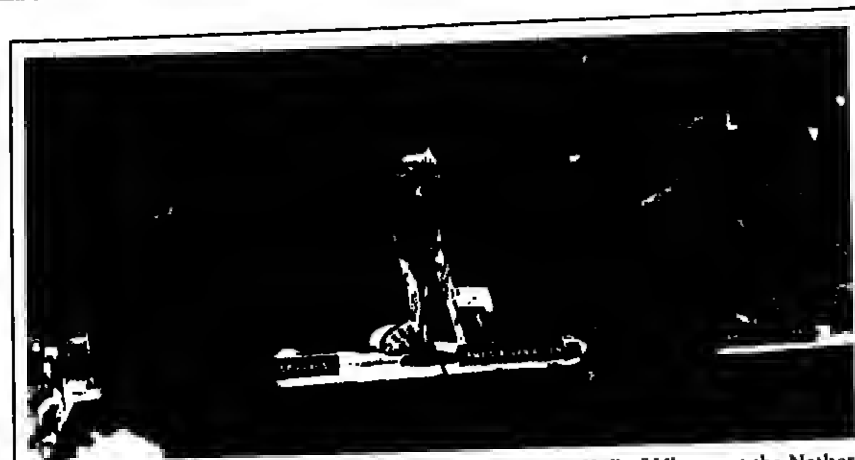

Fig. 1. The Council meeting was held in the glamorous Hall of Mirrors at the Netherland Plaza. President Van Allen enjoys a joke told by CIFT Fund Cochairman, Charles Whitten.

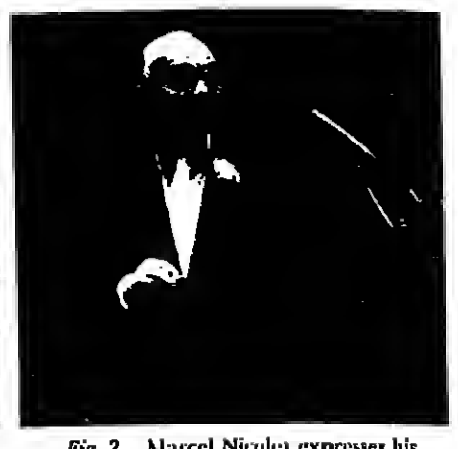

Fig. 2. Marcel Nicolet expresses his thanks and responds to the citation given him as the 1984 Bowie Medalist.

G11-13

The First U.S.-Japan VLBI Test Observation

Noriyuki Kawaguchi (Radio Research Laboratory (RRL), Kashima, Japan and the RRL/NASA Joint Experiment Group) (Sponsor: C. Walter)

A precision very long baseline interferometer, the K-3 system, has been under development since 1979 in accordance with the five-year plan of the Radio Research Laboratories. [illegible]

G11-11A

Feasibility of Gravity Gradient Measurements From a Tethered Subsatellite Platform

[illegible]

GP11-11A

A Late Silurian Paleomagnetic Pole From Limestone Reefs of the Wabash Fm., Indiana, U.S.A.

CHAD McCABE, ROB VAN DER VOO, BRUCE WILKINSON, and KATHLEEN DENNEY (all at: Dept. of Geological Sciences, University of Michigan, Ann Arbor, MI 48109)

A new late Silurian pole has been obtained from reef limestones of Wabash Fm. in central Indiana. [illegible]

GP11-13A

A New Composite (Early Triassic) Paleomagnetic Pole, and a Modified Test for Tectonic Rotations in the Owl Creek Mountains, Wyoming

MARGARET ROONEY, CHAD McCABE, and ROB VAN DER VOO (all at: Dept. of Geological Sciences, University of Michigan, Ann Arbor, MI 48109)

A paleomagnetic test for tectonic rotations in Wyoming's Owl Creek Mountains [illegible]

GP12-09A

A Separation between the Rotational Axes of the Core and the Mantle and its Significance in the Dynamo Process of the Geomagnetic Field

[illegible]

GP31-04A

On Long Motions and Geomagnetic Secular Variation

Raymond Hide (Meteorological Office, Bracknell, England)

[illegible]

H32-11A

TRANSIENT MOVEMENT AND TRANSFORMATION OF INSOLUBLE, SOLUBLE, AND GASEOUS CARBON IN SOIL NEAR WATER SATURATION

A.N. Angelakis (Regional Agricultural Service of Crete, Ministry of Agriculture, GREECE)

D.E. Rolston (Dept. of L.A.W.R., University of California, Davis, CA 95616)

[illegible]

H32A-07

Multiphase Simulation of the Migration of Organic Compounds in a Porous Medium

L.M. Abriola and G.F. Pinder (both at the Department of Civil Engineering, Princeton University, Princeton, NJ 08544)

[illegible]

O32B-05A

Seasonal Production on Georges Bank and the Gulf of Maine with Reference to Hydrographic Factors Controlling Production

[illegible]

O32B-07A

Satellite Sea Surface Flow Estimates in the Vicinity of Northeast Channel, Gulf of Maine

ANDREW C. VASTANO (Department of Oceanography, Texas A&M University, College Station, TX 77843)

Stephen E. BORDERS (SIO/Satellite Oceanography Facility, University of California, San Diego, La Jolla, California 92093)

RUTH E. WITTENBERG (Visibility Laboratory, University of California, San Diego, La Jolla, California 92093)

[illegible]

S32A-12A

THE GUINEAN EARTHQUAKE OF DECEMBER 22, 1983.

R. GAULON (Institut de Physique du Globe, 4 Place Jussieu ...); [illegible]

R. FANDARI, B. TADILI (CNCPRST, Rabat, Maroc) ...

[illegible]

SA22-16 REVISION

Evidence for Magnetosphere-Ionosphere Coupling By Alfven Waves

[illegible]

SM22B-27

Energetic O^+ Ions in the Earth's Magnetosphere

[illegible]

SM22B-23

Suprathermal Solar Wind Heavy Ions in the Plasma Sheet

[illegible]

SM42B-21 POSTER

Effect of Collisions on the Mirror Instability with Application to Venus Flux Ropes

[illegible]

SM42B-23 POSTER

ELECTROMAGNETIC STRUCTURE OF AURORAL CURRENTS

[illegible]

SM42C-15 POSTER

A Theory for the $2f_p$ Radiation Near the Earth's Bow Shock

[illegible]

T22A-07

Seabeam survey of the Indian Ocean triple junction

[illegible]

T22A-13A

Seismicity, attenuation, and subduction of the Ionian [illegible]

T22B-17A

OH^--Related Defects in Olivine: A Single Crystal Infrared Study

[illegible]

T41B-11

Lower Mantle Melting Experiments. Preliminary Results

[illegible]

V42B-16 REVISION

Some Mineral Equilibria in the System [illegible]

4 diopside + $MgCl_2$ + 2HCl = tremolite + $2CaCl_2$
wollastonite + $MgCl_2$ = diopside + $CaCl_2$
wollastonite + 2HCl = quartz + $CaCl_2$ + H_2O

At 600°, for instance, the log equilibrium quotients of the above reactions at 1 m total chloride are respectively, 1.78, 1.94, 5.27, 1.02 and 4.00c.1. These values are compared to available data. On the basis of the HCl dissociation constant of Franck (1956, Zeit. fur Phys. Chem. ...) [illegible]

GAP

Separates

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Particles and Fields— Ionosphere

8535 Interaction between waves and particles PERTURBATIONS OF SUBIONOSPHERIC LF AND MF SIGNALS DUE TO WHISTLER-INDUCED ELECTRON PRECIPITATION BURSTS

D. L. Carpenter, U. S. Inan, M. L. Trimpi, R. A. Helliwell, J. P. Katsufrakis (Space, Telecommunications and Radioscience Laboratory, Stanford University, Stanford, California 94305)

First evidence of whistler-induced burst precipitation effects on subionospherically propagating signals in the LF and MF ranges have been observed at Palmer (L~2.4) and Siple Stations (L~4.3), Antarctica. The occurrence rate on a 37.2 kHz LF signal originating in California was usually comparable to that on the more disturbed VLF paths. At Palmer, examples at 37.2 kHz were seen on 70% of the nights during a March-April, 1983 observing period. [illegible]

J. Geophys. Res., A, Paper 4A0354

8562 Plasma motion, convection, or circulation THE MEASURED MOTIONS [illegible] EQUATORIAL PLASMA BUBBLES

[illegible]

J. Geophys. Res., A, Paper 4A0243